

A Virtual Safety Lab for Automobile Design

by

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1. Introduction

For many years now, the world community has expressed concern over atmospheric pollution. Greenhouse gas emissions have been of particular interest as evidenced by the international Global Warming accord reached recently in Kyoto, Japan. Automobile manufacturers are responding to these concerns by reducing gasoline consumption in the vehicles they produce. One strategy for reducing gasoline consumption is to reduce vehicle weight by employing more aluminum and high strength-to-weight-ratio plastics and composites in the design. However, increased use of these lightweight materials raises issues of occupant safety.

The U. S. automobile industry relies primarily on full-scale crash tests using anthropomorphic dummies to benchmark the safety of new designs. But these full-scale tests can cost up to \$700,000 each and the high cost limits the number of configurations (combinations of vehicle type, occupant anthropometry and collision parameters) that can actually be investigated. This limitation can lead to design flaws that may be dangerous to occupants who, for example, are significantly larger or smaller than the norm. The air bag design that led to numerous fatalities among children and small-statured women in the United States during the mid 1990s provides an excellent case in point. These fatalities were the direct result of the impact of the inflating air bag on the occupants' heads, frequently during collisions that would have otherwise been survivable.

In order to provide a less expensive method for evaluating the safety of new automobile designs, a method which complements the full-scale crash tests that will always be a necessary adjunct, Los Alamos National Laboratory (LANL) began development of a Virtual Safety Lab (VSL) in 1995. When fully implemented, the VSL will enable automobile designers to simulate a full-scale crash test using detailed finite element models of both the vehicle and its occupants. Development of a Deformable Human Body Model (DHBM) for use in the VSL and other civilian and military applications was supported by the Los Alamos National Laboratory Program Development and Director's Reserve Funds.

The VSL provides a "point and click" graphical user interface that enables a designer to select a particular vehicle configuration, specify occupant anthropometry, import detailed biomechanical models for specific body components, set collision parameters, execute a test calculation, view animated results and assess the potential for occupant injury, all without requiring that the designer have expertise in computational mechanics and finite element analysis.

The human occupant model developed at Los Alamos is based on a finite element model of the Hybrid III Anthropomorphic Test Dummy (50th percentile group, male) developed

by the National Crash Analysis Center (NCAC) at Georgetown University under contract to the National Highway Traffic Safety Administration. Version 1 of the NCAC dummy model has 16,000 nodes (computational points) and is available on the Internet at <http://gwuva.gwu.edu/ncac/public.html>. Los Alamos has adopted this model and added two critical enhancements that greatly increase its utility for a variety of applications. First, we added the capability to scale the model based on international anthropometry¹ (20 regions worldwide, 5th, 50th and 95th percentile groups, male and female, all projected to the year 2000) or on the basis of ten individually specified anthropometric measurements. The regions included in the international anthropometry database are listed in Table 1 and the ten anthropometric measurements used in the scaling procedure are listed in Table 2.

Table 1. International Anthropometry Regions in the VSL

- | | |
|-------------------------------------|-------------------------------|
| 1. North America | 11. West Africa |
| 2. Latin America | 12. Southeastern Africa |
| 3. L. America (Europ.-negroid pop.) | 13. Near East |
| 4. Northern Europe | 14. North India |
| 5. Central Europe | 15. South India |
| 6. Eastern Europe | 16. North Asia |
| 7. Southeastern Europe | 17. South China |
| 8. France | 18. Southeast Asia |
| 9. Iberian Peninsula | 19. Australia (European pop.) |
| 10. North Africa | 20. Japan |

Table 2. Anthropometric Measurements Used in VSL Scaling

- | | |
|--------------------------------|-------------------------|
| 1. Head Circumference | 6. Forward Reach |
| 2. Head Length | 7. Sitting Hip Breadth |
| 3. Head Breadth | 8. Erect Sitting Height |
| 4. Bideloid Shoulder Breadth | 9. Buttock-Knee Length |
| 5. Biacromial Shoulder Breadth | 10. Knee Height |

Secondly, we have provided the capability to substitute detailed biomechanical component models for the corresponding dummy components. Appropriate detailed component models for the thorax and lower body are under development at Wayne State University and NCAC, respectively. To demonstrate the substitution capability of the VSL and provide a research tool for studying blunt body trauma to the head, we have developed a 60,000-node finite element model of the human head.

2. The LANL Head Model

The LANL head model is based on the Visible Human Dataset provided by the National Library of Medicine². The first step in the development process was to convert the cross-sectional information provided by the dataset to three-dimensional objects representing the three primary physiological layers. This task was accomplished by: 1) displaying the cross sections one at a time and marking the boundaries between the outer soft tissue, the skull and the brain; and 2) assembling the partitioned cross sections into three separate three-dimensional objects. The outer soft tissue, skull and brain objects generated by this method are presented in Figs. 1, 2 and 3, respectively. These three-dimensional objects have a resolution of 2 millimeters, which is sufficient to make the Visible Human subject easily recognizable.



Figure 1. Three-dimensional Outer Soft Tissue Object for LANL Head Model



Figure 2. Three-dimensional Skull Object for LANL Head Model

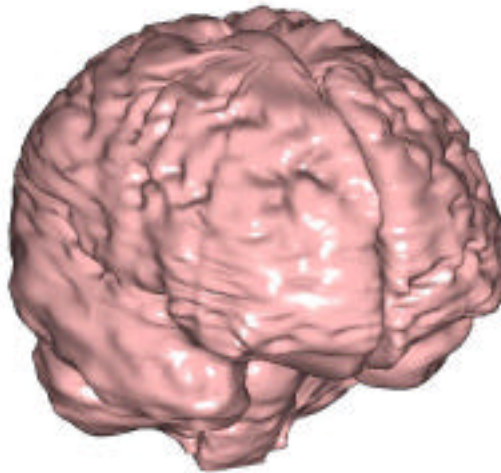


Figure 3. Three-dimensional Brain Object for LANL Head Model

The next step was to construct finite element meshes on the three objects representing the head. This process has been completed for the outer soft tissue and for the brain, but is only partially complete for the skull. The finite element model of the outer soft tissue

layer is presented in Fig. 4. This model has a resolution of about 4 millimeters, which is fine enough that the subject is still easily recognizable.

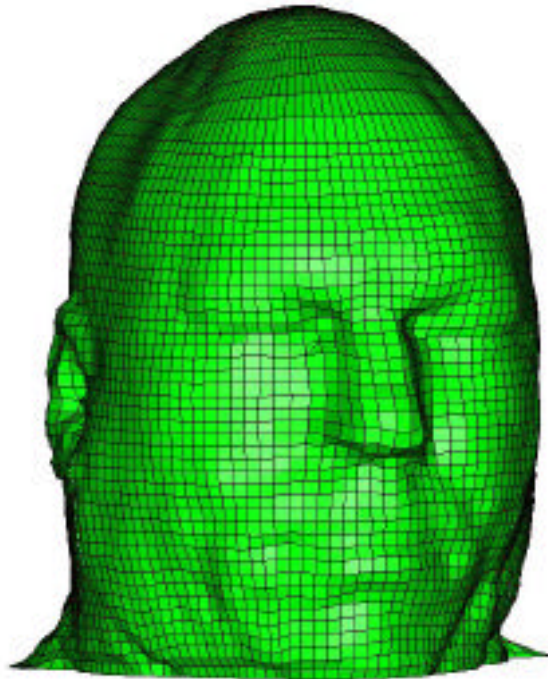


Figure 4. The LANL Head Model (external soft tissue)

3. The Virtual Safety Lab Toolbox

The VSL has been incorporated into the Khoros³ program as an application toolbox. Khoros is a software integration environment developed by Khoral Research, Inc., in Albuquerque, New Mexico. The VSL toolbox, which is accessed by a cascading pulldown menu called *Glyphs* (see Fig. 5), consists of five component tool drawers. (The word “Glyphs” is simply another name for “Icons.”) The five tool drawers available in the VSL are:

1. *Visualization*
2. *Occupant Models*
3. *Occupant Operations*
4. *Vehicle Models*
5. *Crash Test*

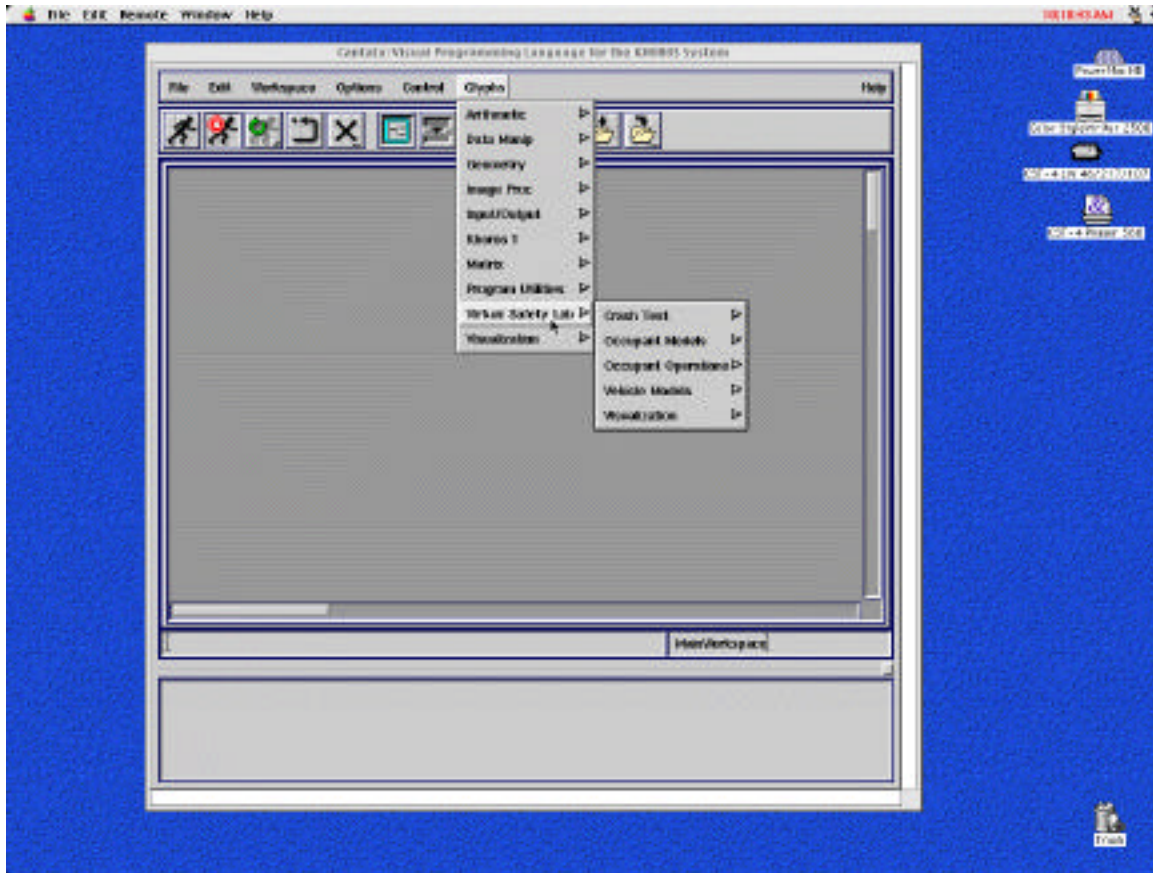


Figure 5. The *Virtual Safety Lab* Toolbox in Khoros

Each tool drawer contains a set of tools. When a tool is selected from a tool drawer, the outline of a glyph appears on the work space. The glyph may be moved to the desired location with the mouse and positioned there by clicking the mouse button. Procedures are created by stringing together a series of tools in an appropriate sequence. The contents of the five tool drawers and their use in developing procedures for vehicle crash analysis are described in the following sub-sections.

Visualization:

The *Visualization* tool drawer (see Fig. 6) contains two tools. The first tool, *Display Current Model*, is used to provide a three-dimensional image of the finite element model being constructed for a specific crash simulation; it can be inserted at any point in a sequence of operations and will, as the name implies, display the current state of the finite element model being developed.

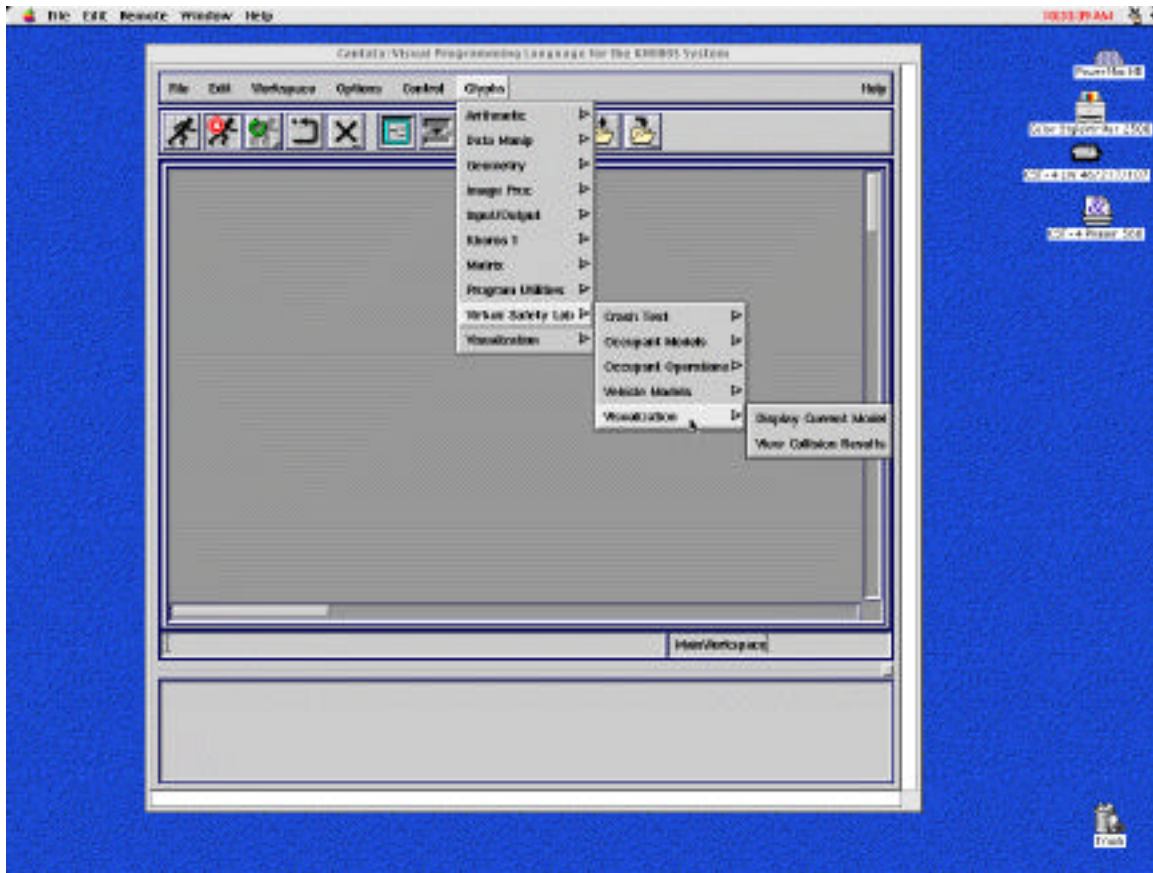


Figure 6. The *Visualization* Tool Drawer

The second tool, *View Collision Results*, provides access to animated results and other graphical information at the conclusion of a crash simulation. This glyph can only be used at the end of a sequence of operations that defines and executes a crash calculation.

Occupant Models

The *Occupant Models* tool drawer (see Fig. 7) provides direct access to the Hybrid III 50th percentile male Anthropomorphic Test Dummy model or to any other derivative model that the user may have previously constructed using tools from the *Occupant Operations* tool drawer. One such derivative model is the *South China Woman (5th percentile)*, which is included as an example in the *Occupant Models* tool drawer. Alternatively, the user can choose the *Select Occupant Model* glyph, which can then be used to select an occupant model dynamically from the glyph itself at any point during the construction of a crash simulation procedure.

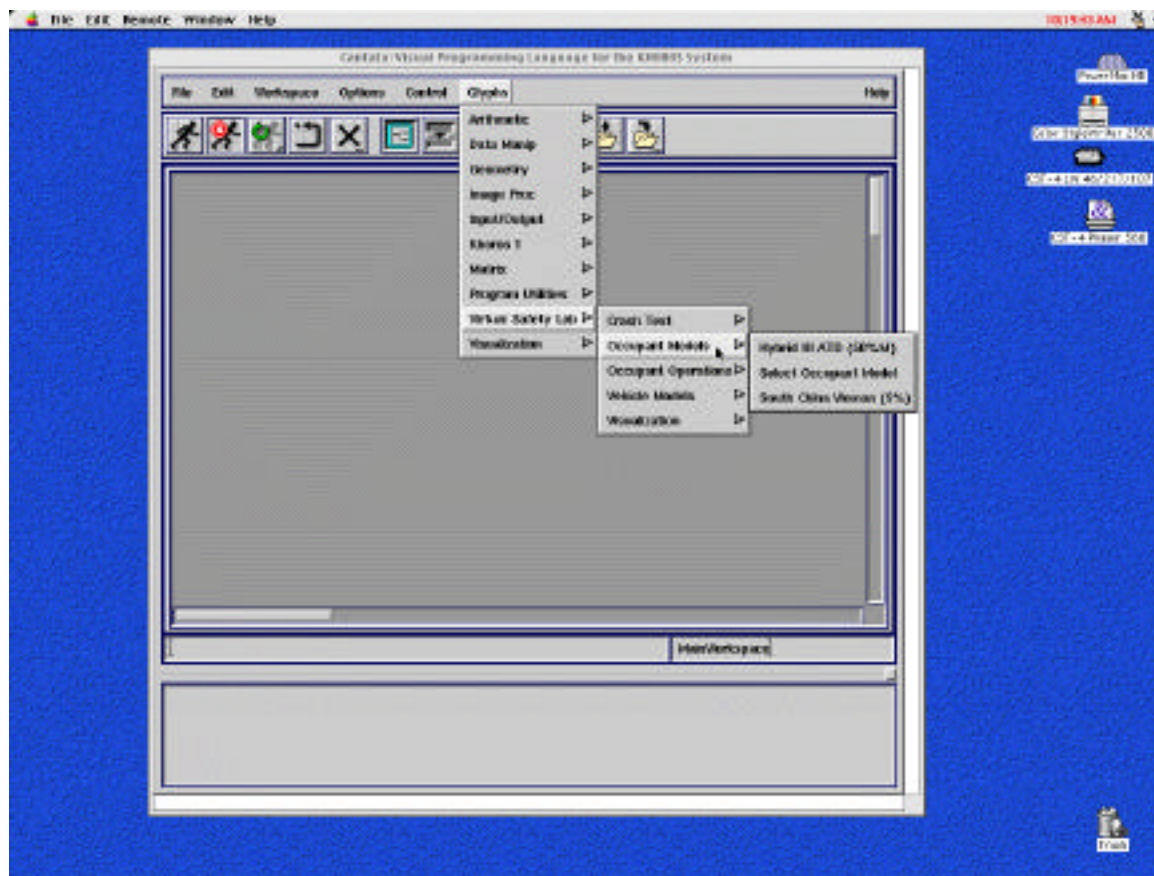


Figure 7. The *Occupant Models* Tool Drawer

An example of a simple VSL procedure, involving selection of the *Hybrid III ATD (50%M)* glyph from the *Occupant Models* drawer and display of that model using the *Display Current Model* glyph from the *Visualization* tool drawer, is depicted in Fig. 8. The control connection between the two glyphs is generated by clicking on the small square control ports on each glyph in the proper sequence.

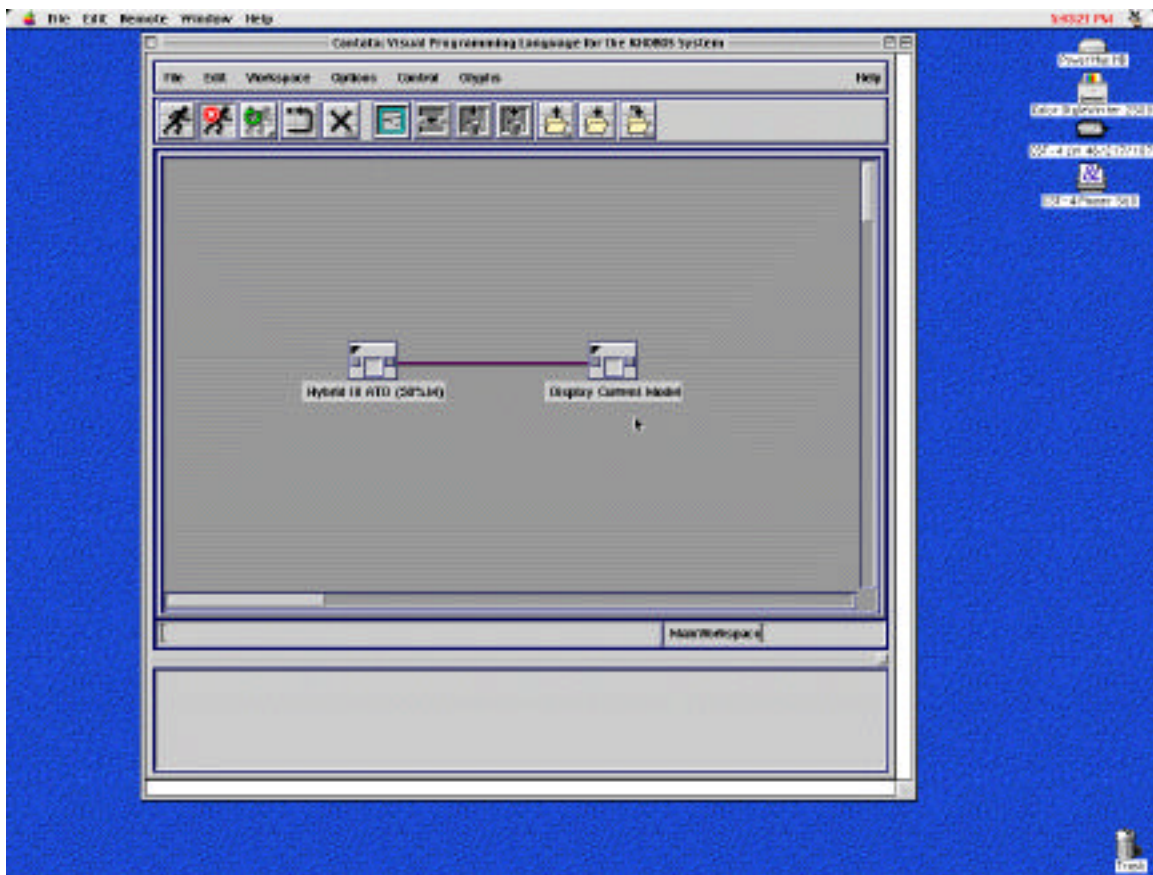


Figure 8. A Simple Virtual Safety Lab Procedure

The procedure is executed by clicking on the running man icon in the upper left corner of the workspace. The result of executing this simple procedure is presented in Fig. 9, where the unmodified Hybrid III dummy model has been displayed using the I-DEAS⁴ mesh generation software package.

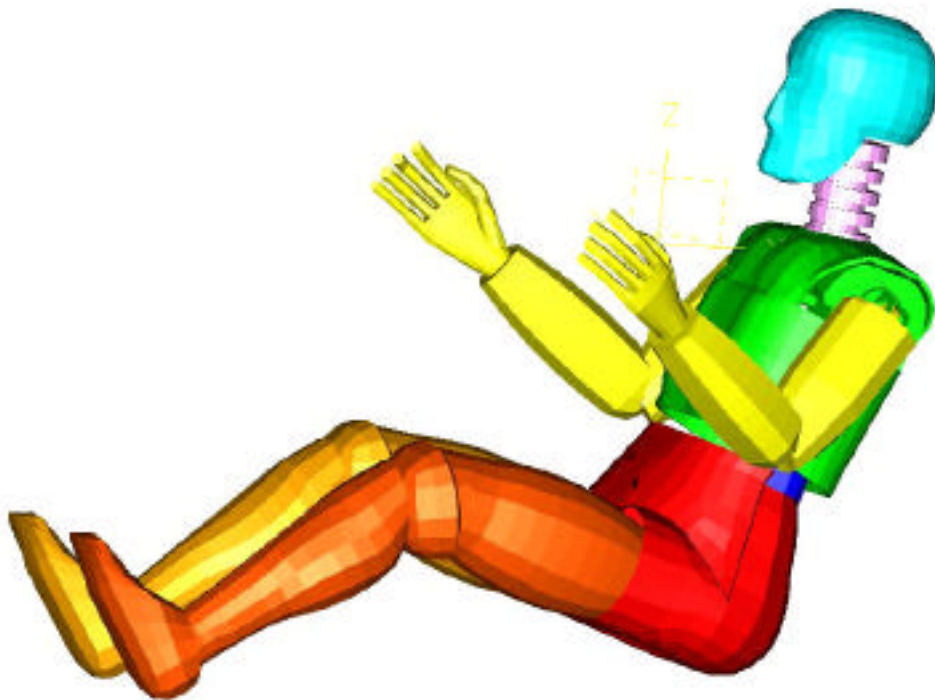


Figure 9. The Hybrid III 50th Percentile Group Male ATD

Occupant Operations

The *Occupant Operations* drawer contains three tools, as depicted in Fig. 10. These tools are capable of modifying the originally selected occupant model in several ways. The *Substitute Bio Component* glyph enables the user to substitute a detailed biomechanical component model for the corresponding dummy component; specification of which component is to be substituted is made from a special glyph menu called a “pane,” which is accessed by clicking on the small black triangle in the upper left corner of the glyph.

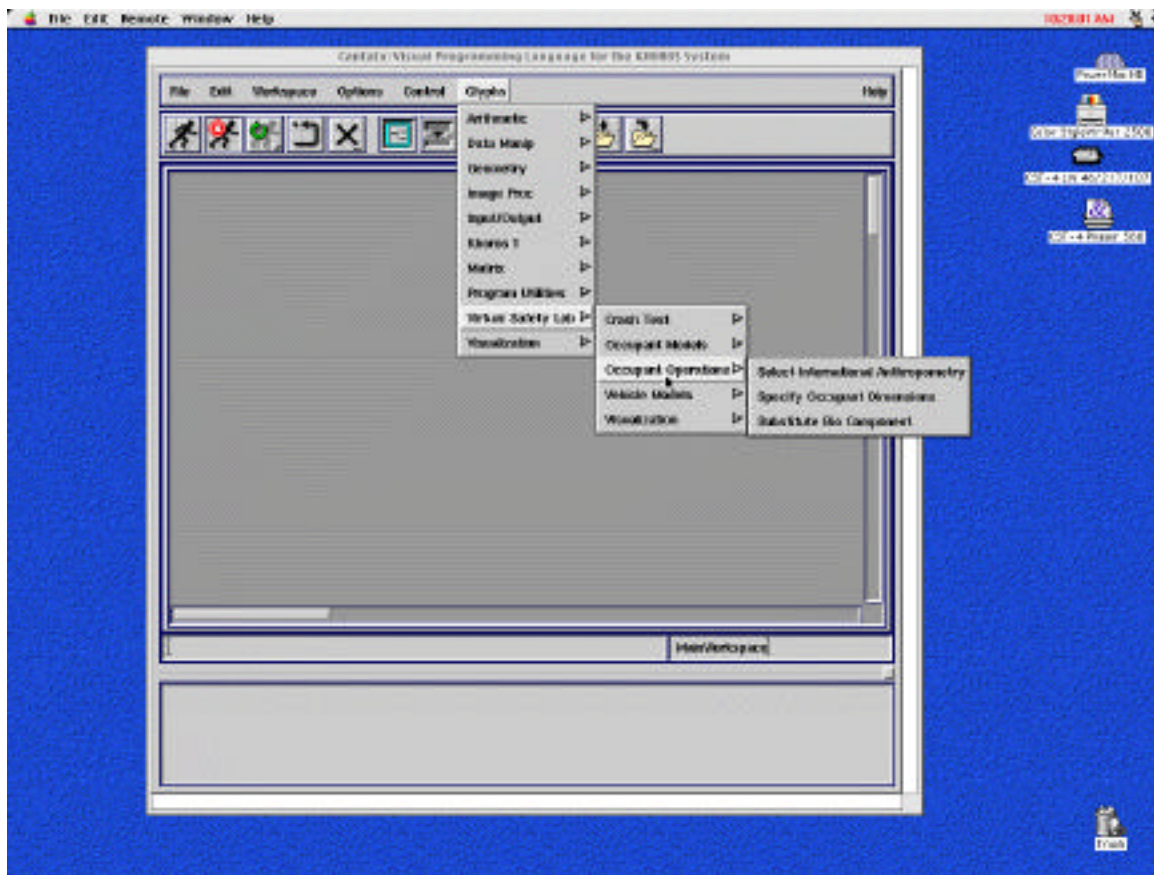


Figure 10. The *Occupant Operations* Tool Drawer

The user may also scale the occupant model by using the *Select International Anthropometry* glyph. In this case, the anthropometric region, percentile group and sex are selected from the pane menu associated with the glyph. An example is presented in Fig. 11, where the Hybrid III model is first modified by substituting the LANL Head Model and subsequently scaled to represent a 5th percentile group woman from the South China region. After making the appropriate selections in the pane menus, the panes are closed by clicking on the *Close* buttons.

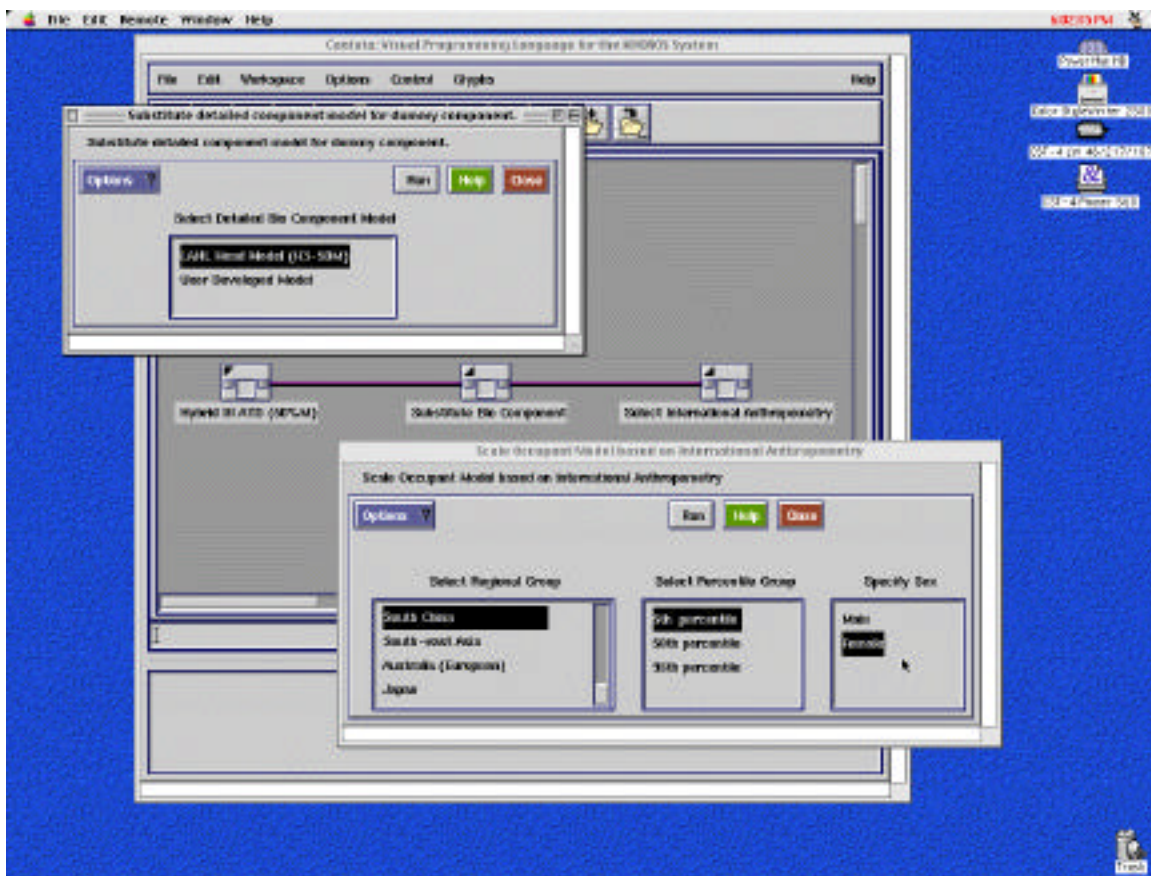


Figure 11. Example Procedure for Setting Up Occupant Model

As an alternative to selecting an international anthropometric group, the user can choose the *Specify Occupant Dimensions* glyph, which allows characterization of the occupant by specifying each of ten anthropometric measures. Again, the dimensions are entered on the pane menu of the glyph, as illustrated in Fig. 12. The dimensions appearing on the menu in Fig. 12 are default values which represent the Hybrid III 50th percentile group male. These values must be changed by the user in order to affect an alteration of the original dummy model.

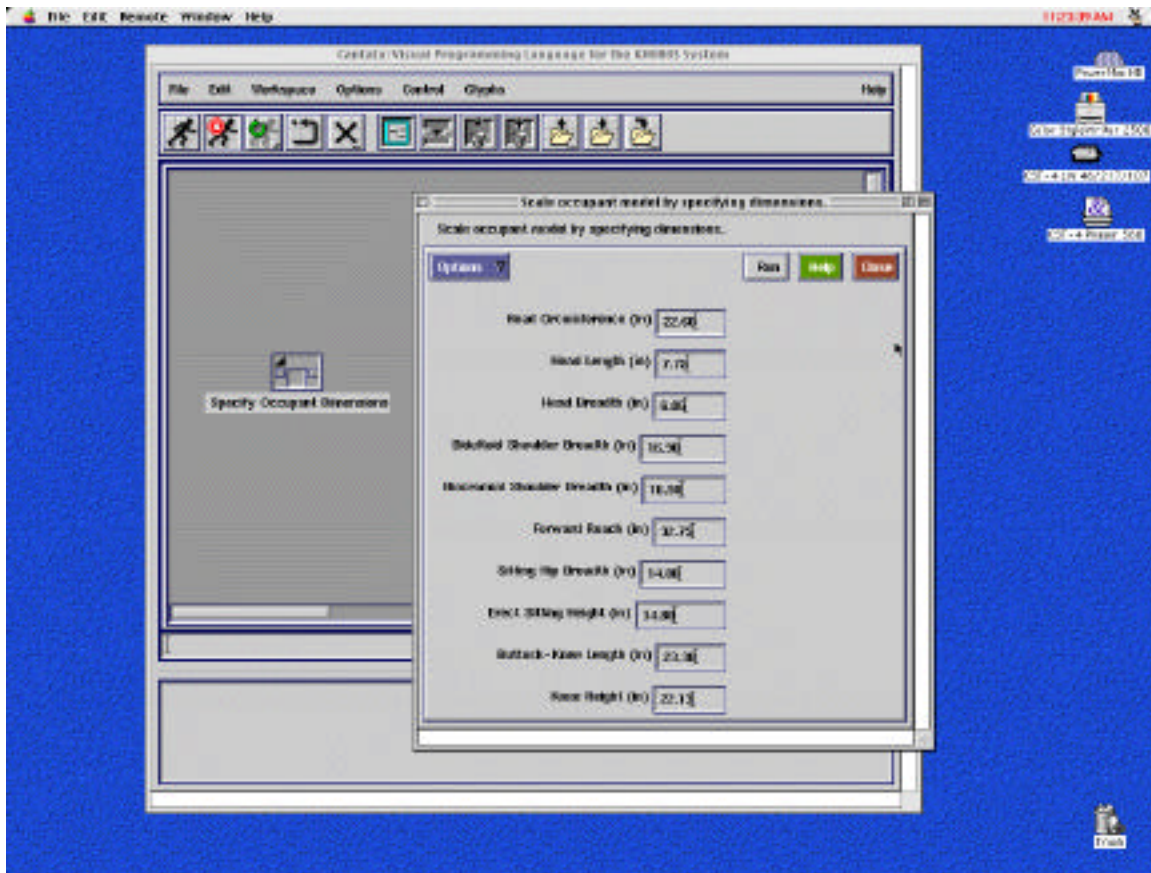


Figure 12. The *Specify Occupant Dimensions* Glyph

Vehicle Models

Two highly simplified vehicle models (*Rigid Test Vehicle* and *Deformable Test Vehicle*) were developed by LANL and included in the *Vehicle Models* tool drawer to provide a test and demonstration capability for the VSL (see Fig. 13). Ordinarily, detailed vehicle models would be provided by the user; the *Vehicle Models* tool drawer contains a *User Defined Vehicle* glyph for that purpose. The *Vehicle Models* tool drawer also contains a *Select Vehicle* glyph that allows the user to pick a vehicle for analysis from the pane menu associated with the glyph.

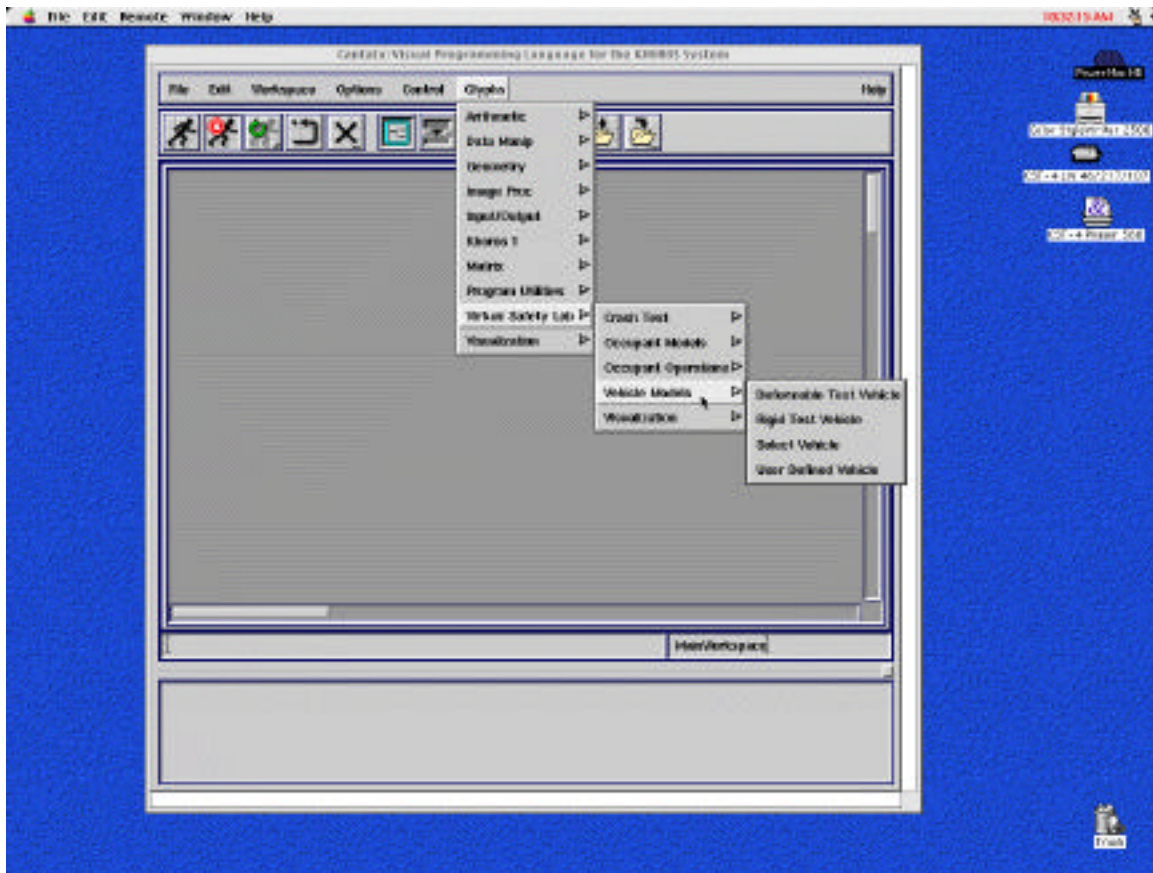


Figure 13. The *Vehicle Models* Tool Drawer

Crash Test

The *Crash Test* tool drawer contains four glyphs that are used to set up and execute a simulated crash test (see Fig. 14). The first glyph, *Combine Veh. & Occ.*, takes a selected occupant model and places it in a selected vehicle model. The “combine” operation rotates the occupant model to the correct orientation, translates the model so that the buttocks are 0.5 millimeter above the vehicle seat bottom and then translates the model a second time to provide a 0.5 millimeter standoff distance between the occupant back and vehicle seat back.

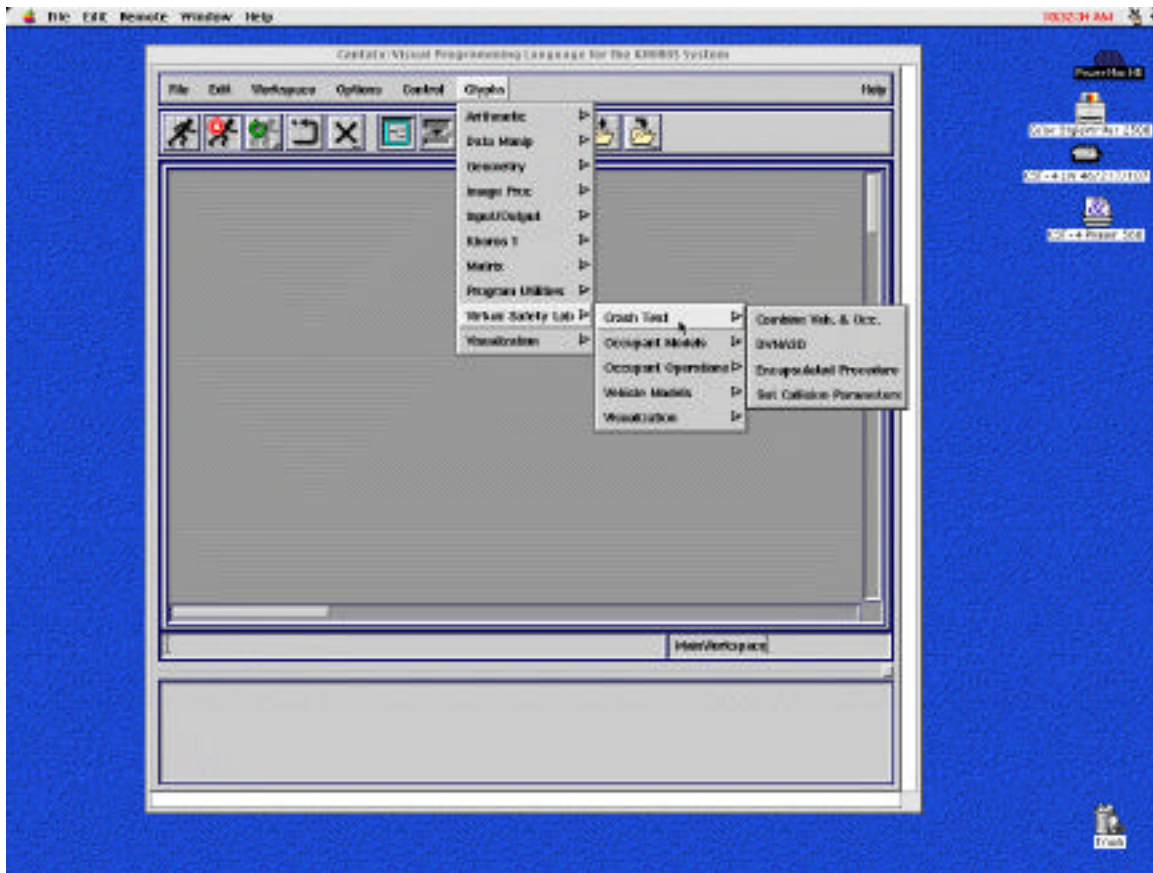


Figure 14. The *Crash Test* Tool Drawer

Figure 15 illustrates a procedure for defining the occupant, selecting a test vehicle, combining the occupant and vehicle models and displaying the resulting combined model. The pane menu for the *Select Vehicle* glyph has been opened and the *Rigid Test Vehicle* has been selected.

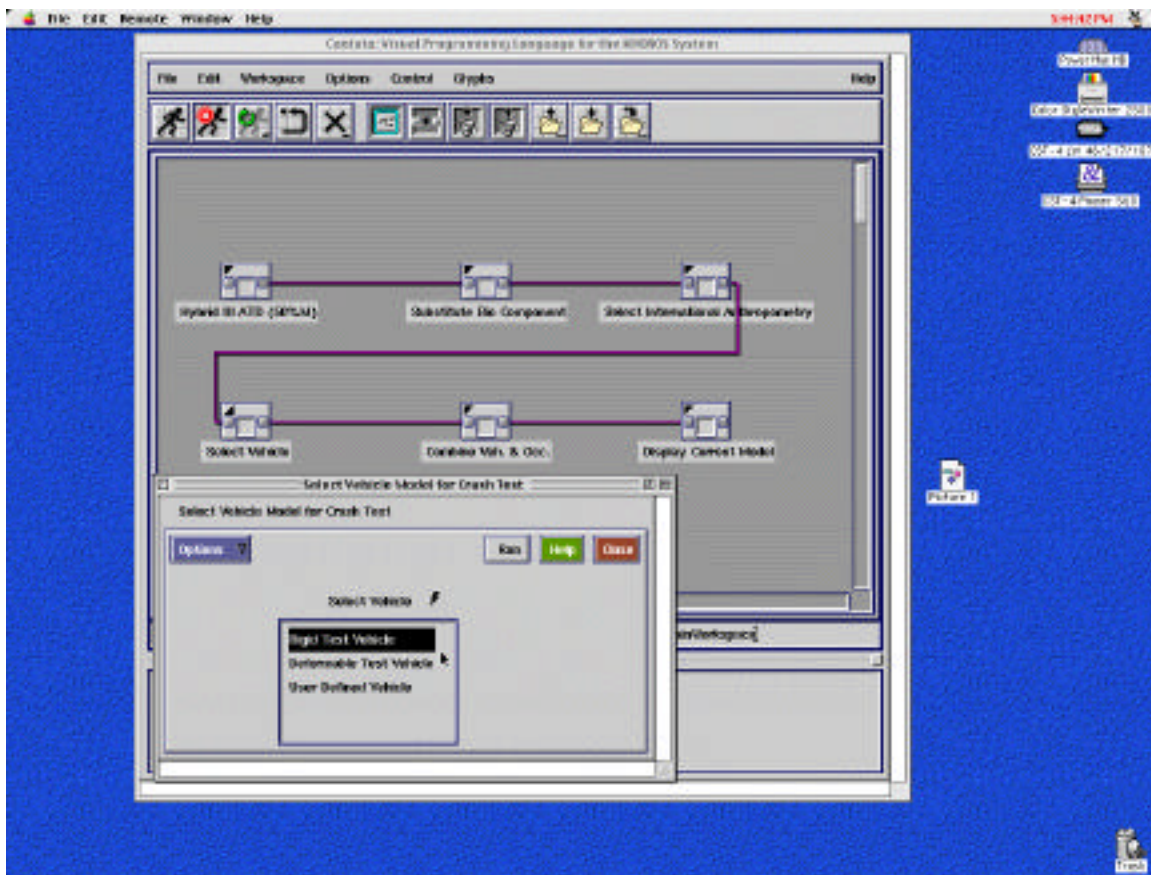


Figure 15. Example Procedure for Selecting the Hybrid III Dummy Model, Substituting the LANL Head Model, Scaling to Represent a 5th Percentile Group South China Woman, Selecting the Rigid Test Vehicle, Combining Vehicle and Occupant Models and Displaying the Result

The result of executing this procedure is presented in Fig. 16; here the LANL head model has been substituted for the dummy head and the combination has been scaled to represent a 5th percentile group South China woman. Some of the outer layer of soft tissue on the head model has been cropped along the back and bottom of the skull to make it compatible with the dummy neck to which it is attached. The occupant model is seated in the *Rigid Test Vehicle*.

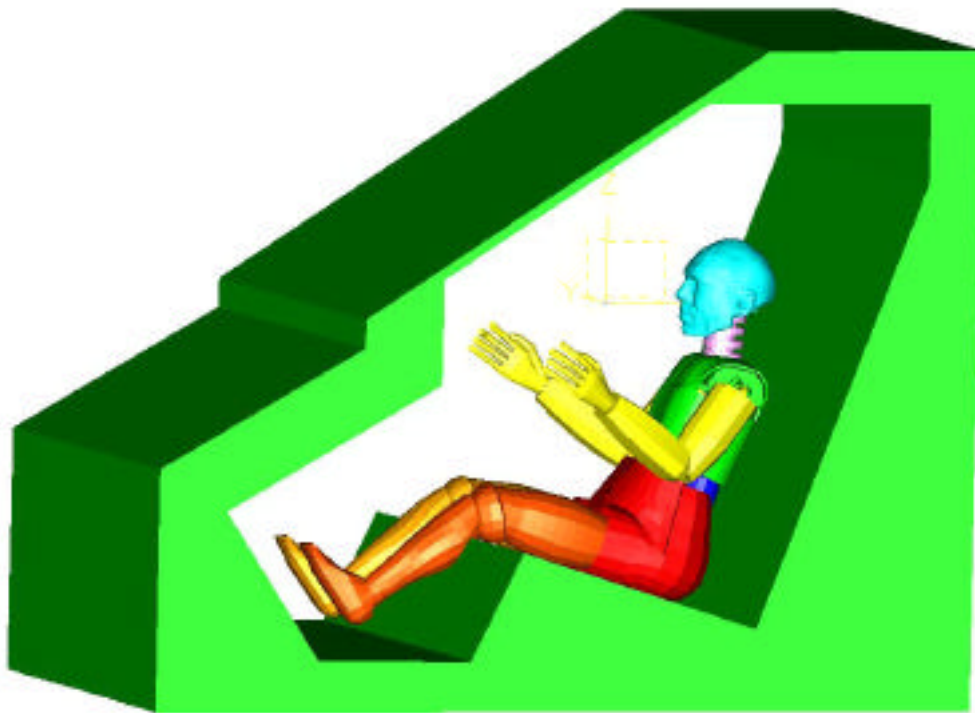


Figure 16. Fifth Percentile Group South China Woman with LANL Head Model Seated in Rigid Test Vehicle

After placing the occupant in the test vehicle, the user can select the *Set Collision Parameters* glyph to provide a mechanism for specifying the vehicle speed and direction relative to a rigid test barrier. The collision parameters are entered in the pane menu that is associated with the “collision parameter” glyph, as illustrated in Fig. 17.

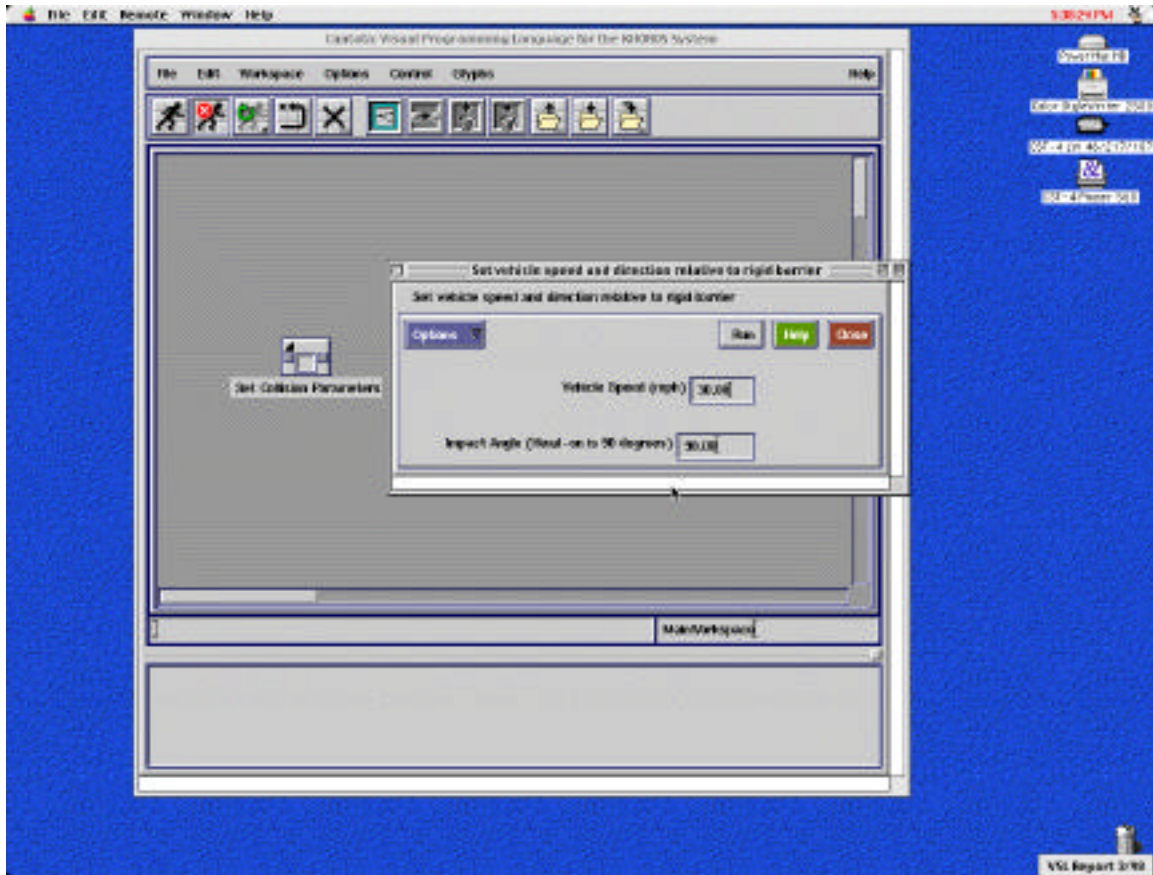


Figure 17. The *Set Collision Parameters* Glyph

The *DYNA3D* glyph is used to execute the finite element calculations that are set up by defining the occupant, vehicle and collision parameters. This glyph, which is not yet operational in the VSL, will use the DYNA3D⁵ explicit finite element code developed at Lawrence Livermore National Laboratory to perform the computations.

The *Encapsulated Procedure* glyph in the *Crash Test* tool drawer contains a complete crash test procedure that can be modified by introducing new data through menus in the glyph panes. This glyph differs in appearance (see Fig. 18) and function from the other glyphs in the VSL. By clicking on the white triangle in the upper right corner of the glyph, the user can display the encapsulated procedure on the worksheet, as illustrated in Fig. 19.

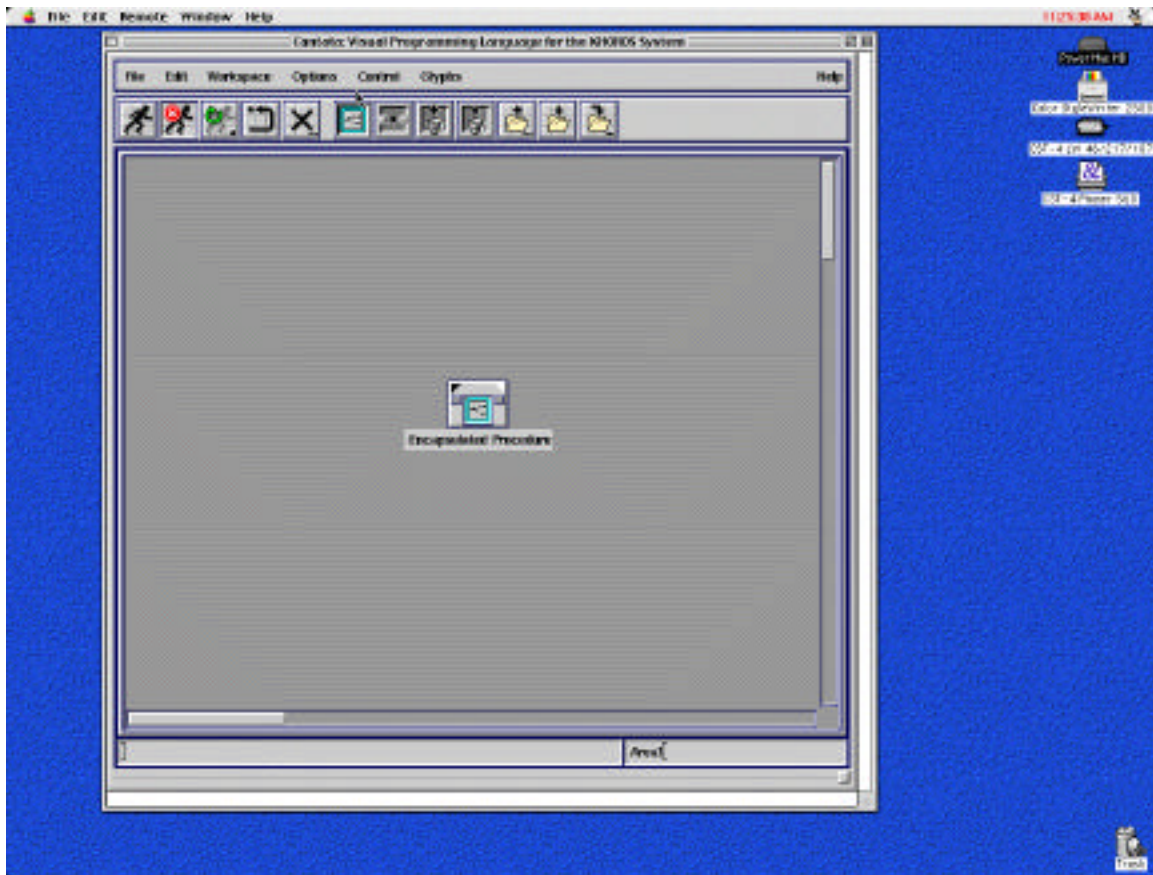


Figure 18. The *Encapsulated Procedure* Glyph

Note that all glyphs that require user input through pane menus have been located on the left side of the workspace. This arrangement makes it easy for the user to step through the glyphs, opening the panes in sequence, selecting the desired options and entering the necessary data as he/she sets up a crash test simulation.

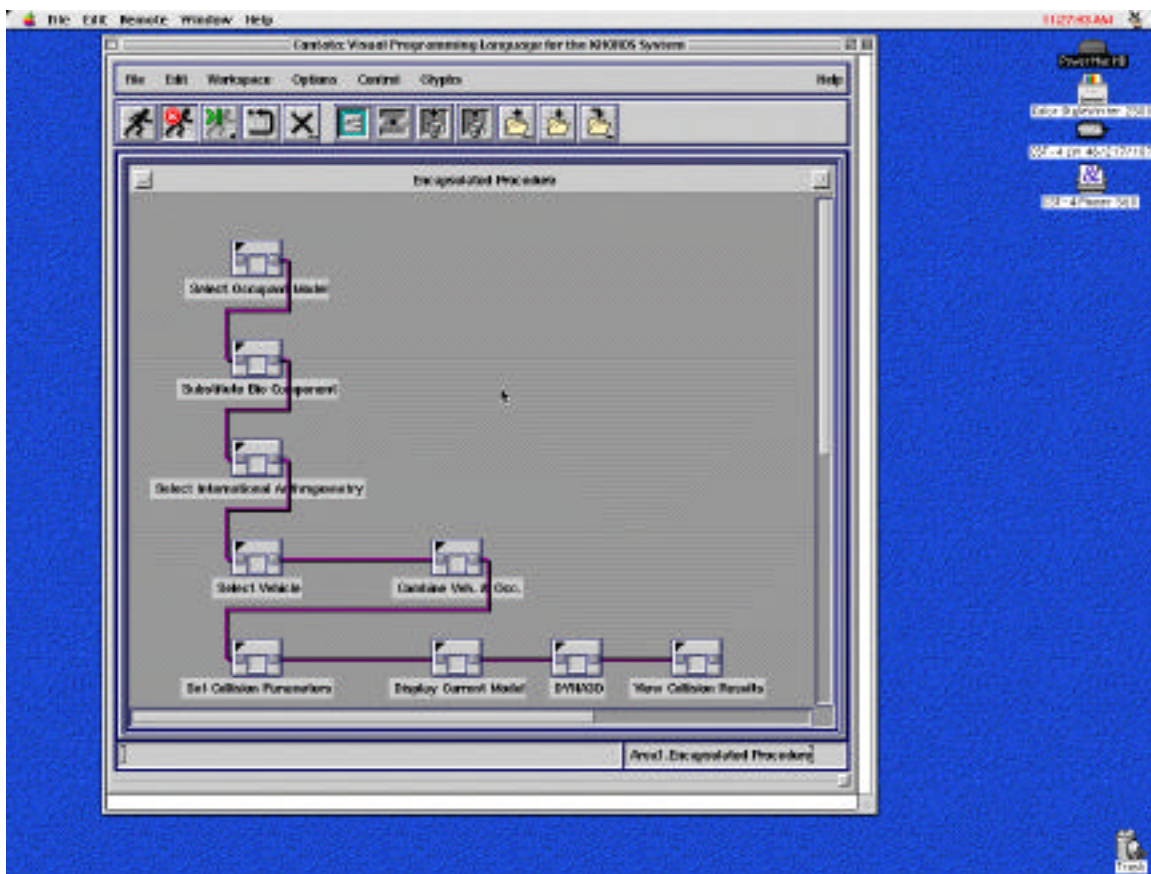


Figure 19. Display of Encapsulated Crash Test Procedure

It should be noted that the process of encapsulating procedures is an option provided by the Khoros software through the *Control* menu, as indicated in Fig 20. Note that the last item in the menu is *Encapsulate Workspace*. The user simply sets up the desired procedure by selecting the needed glyphs and joining them with control connections in the proper sequence. Then the procedure is encapsulated by selecting the *Encapsulate Workspace* option from the *Control* menu; at that point the user will be asked what to name the new procedure and where (toolbox and tool drawer) to store it.

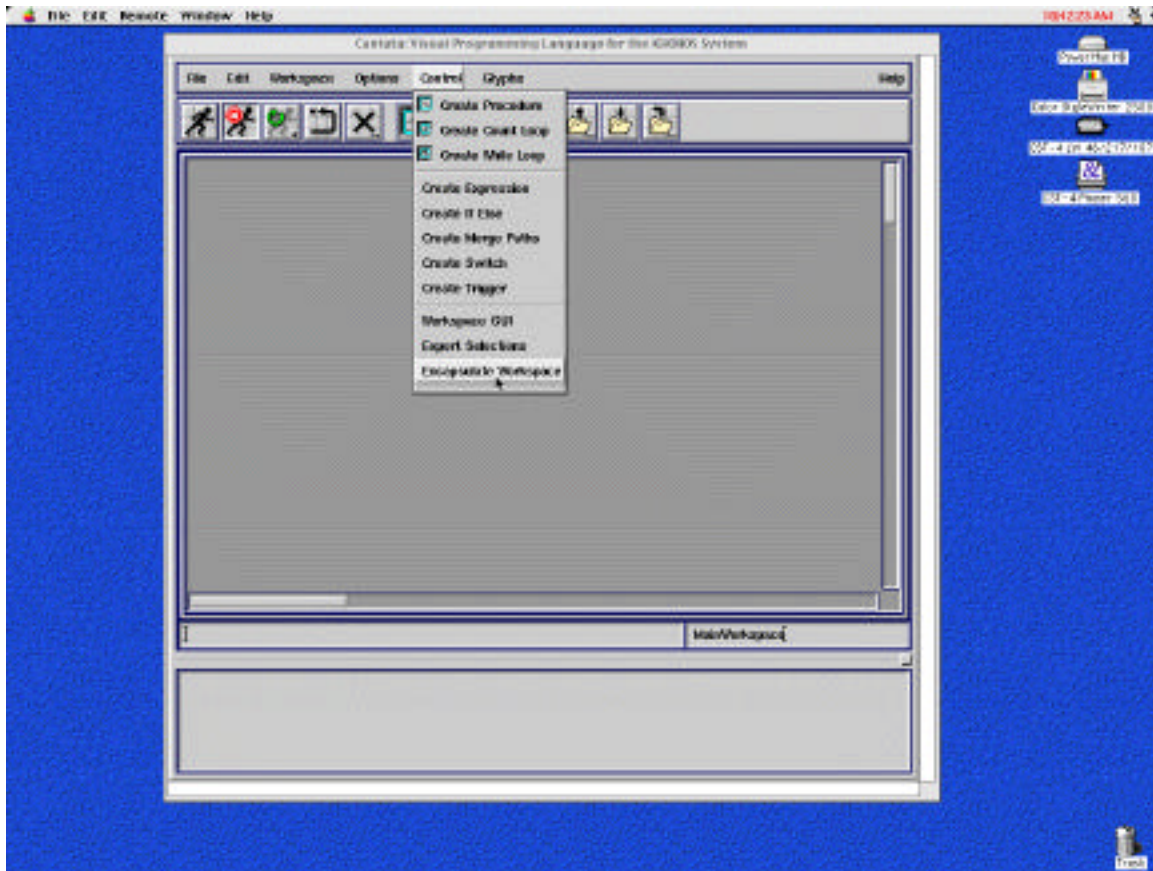


Figure 20. The *Control* Menu Showing the *Encapsulate Workspace* Glyph

In addition, note that the *Control* menu provides the capability to set up loops and conditional branches within a procedure. Although we have not used these options to date, they would clearly be very useful for setting up a series of crash test simulations to explore the effect of variations in selected parameters on occupant safety.

4. Recommendations for Further Development of the Virtual Safety Lab

Initial VSL development will be complete when the LANL head model is finished and the *DYNA3D* and *Display Animated Results* glyphs are made fully operational. These tasks should be completed by early 1999. At that time, the VSL will be available for set up for use at automobile manufacturing facilities.

Several additional tasks are recommended to improve the accuracy and realism of the human occupant model. First, Version 2 of the Hybrid III dummy model should be incorporated into the VSL as soon as it becomes available from NCAC. Version 2 will provide a more accurate representation of the arms, pelvis and legs than Version 1. For example, the discontinuity between the dummy pelvis and thighs (evident in Figs. 9 and 16) does not appear in the physical Hybrid III dummy and will be eliminated in the Version 2 model. Ahmed Nouredine, the Hybrid III Model project leader at NCAC, estimates that Version 2 will be available sometime in May 1998.

Second, female and child Anthropomorphic Test Dummy models should be added to the *Occupant Models* tool drawer of the VSL as soon as such models are become available from NCAC or other biomechanics research groups. Although the Hybrid III 50th percentile male model currently used in the VSL can be (and is) scaled to represent female or child occupants, the quality and realism of the results would be greatly improved if accurate female and child reference models, respectively, were used in the scaling process.

In addition, we recommend that the scaling procedure currently used in the VSL be refined by introducing separate longitudinal and transverse scale factors for each body segment. The current method allows for independent scaling of seven body components (head, neck, torso, arms, lumbar spine, pelvis and legs) on the basis of ten specified anthropometric measurements. At present, each scaled component retains geometric similarity with the original Hybrid III component. Thus the current scaling procedure cannot represent weight and body type variations within the sub-groups defined by each set of specified parameters. Incorporation of longitudinal and transverse scaling for each body segment into the VSL will make the occupant model perfectly general in that any body type whatsoever could be represented. This refinement of the scaling procedure will not be difficult to implement, because we have already developed methods for modifying the Hybrid III model on a component by component basis.

5. Conclusion

The VSL provides a point-and-click capability for simulating vehicle collisions with realistic human occupant models. The occupant model may be scaled to represent 5th, 50th or 95th percentile male or female groups from 20 regions worldwide (all projected to the year 2000) or on the basis of ten individually specified anthropometric measurements. Detailed biomechanical component models (as available) may be substituted for corresponding dummy components to gain additional insight on injury potential to specific parts of the body. A detailed head model based on the Visible Human Dataset (from the National Library of Medicine) is provided for studying blunt body trauma to the head.

References

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3. *Khoros Pro User’s Guide*, Khoral Research, Inc., Albuquerque, NM, 1996. Khoros is a trademark of Khoral Research, Inc.
4. *I-DEAS Master Series 2.0/Exploring I-DEAS Simulation : Structural Dynamics* Research Corporation, Milford, OH, 1994.
5. Whirly, R. G., Engelmann, B. E., Hallquist, J. O. *DYNA3D: A Nonlinear, Explicit, Three-Dimensional Finite Element Code For Solid and Structural Mechanics—User Manual*, Lawrence Livermore National Laboratory, 1993.